Toward a Methodology for Tsunami Risk Analysis

A proposal submitted to the NTHMP Mitigation and Education Subcommittee by:
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Goal: The proposed project will develop a methodology for tsunami risk assessment that integrates probabilistic tsunami hazard analysis with quantitative metrics of socioeconomic vulnerability. This method will yield site-specific, map-based risk assessments that benefit emergency and land-use managers. The inclusion of this method as a module in HAZUS or other loss-estimation applications will be explored as a potential means of converting research to operations.

Motivation: NTHMP Performance Measures and Milestones include a strategy to "support a research effort to develop U.S. tsunami risk assessment methodologies" in order to "develop quantitative tsunami hazard analysis techniques including source determination and probability of occurrence" and "determine applicability of economic and loss estimation tools (e.g. HAZUS) by 2010" (Oppenheimer et al., 2008).

Background: Risk is defined in a number of ways, but invariably invokes probabilistic assessments that capture the intersection of natural hazards and vulnerable human systems. The NTHMP working definition of risk is "the product of the probability of the occurrence of a tsunami times the loss of property and life due to the tsunami" (Oppenheimer et al., 2008). The United Nations International Strategy for Disaster Reduction defines risk as "the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between hazards and vulnerable conditions" (UN/ISDR, 2004). Vulnerability is defined conceptually as "the conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards" (UN/ISDR, 2004). Turner et al. (2003) further defines societal vulnerability as a function of the exposure, sensitivity and resilience of an individual or community system relative to a natural hazard. Because of the inherent complexity of social, structural, and economic sub-systems in coastal communities, assessing societal risk to tsunamis requires a suite of approaches that are geared for various societal issues (e.g., population sensitivity, structural loss, financial exposure) and potential human adjustments to minimize tsunami risk (e.g., evacuation planning, structural mitigation, insurance options). In short, the tools and data used for tsunami risk analysis should vary based on the intended need of the practitioner. For example, economic and land-use planning may benefit from probabilistic loss estimates, whereas education and response planning concerns may be better informed by other non-probabilistic, quantitative approaches (see Wood and Soulard, 2008). In addition, effective risk characterizations are not simply analytical exercises, but also include active deliberation with affected parties or with agencies that have risk-reduction responsibilities to ensure values and priorities are included (National Research Council, 1996). Risk analysis and deliberation are complementary, iterative activities; deliberation guides what analysis is needed and analysis informs risk-reduction deliberations.

Approach: This project is viewed as a first step in developing a portfolio of analytical tools to characterize societal risk from tsunamis. Our primary focus for this project is on methods that support emergency managers in their efforts to develop realistic evacuation strategies, response plans, and education efforts. This initial effort will focus only on tsunami-related risks and not explore the compounding societal risks associated with earthquake hazards (e.g., ground shaking, liquefaction) that precede near-field tsunamis. Our tsunami-risk approach involves integrating spatially-referenced estimates of tsunami hazards and vulnerable human systems to these hazards. The development of each factor will include the following work.

- <u>Study area:</u> We will focus on Ocean Shores, Washington, based on several reasons. First, the area has high exposure to tsunami hazards, due to the large amount of individuals and assets in tsunami-prone areas. Approximately 4,000 people (based on 2000 Census data) live in the tsunami-hazard zone (Wood and Soulard, 2008). The Quinault Beach Resort and Casino, which is on tribal land in Ocean Shores and is owned and operated by the Quinault Indian Nation, represents a significant evacuation issue and is one of the largest employers in the area. With the high concentration of people and economic assets in tsunami-prone areas, city and tribal officials need a better understanding of their risks from tsunamis to develop a sound tsunami preparedness program. Second, the inclusion of the Quinault Indian Nation in our study area provides us with the opportunity to document cultural differences in the use of tsunami risk products and the development of risk-reduction actions. Third, we have worked extensively with residents, officials, and community and Quinault Indian Nation leaders in Ocean Shores in the past; therefore, community engagement for this project can build on existing trust and credibility with the community. Fourth, modeling studies have been conducted for Ocean Shores, Washington, using the NOAA-approved tsunami propagation and inundation model known as the Method of Splitting Tsunami, or MOST model (Figure 1; Venturato, et al. 2007). Fifth, base socioeconomic data (e.g., land cover, population, economic, parcel values, critical facilities) have been collected for this area as part of a regional study of community vulnerability to tsunamis in Washington (Figure 2; Wood and Soulard, 2008). Having the base regional data in hand allows us to focus on the collection of additional local data (e.g., structures, roads). We will leverage these earlier efforts to characterize tsunami hazards and community vulnerability in this community.

- Hazard Factor: González et al. (in review) describe a formal methodology for conducting a probabilistic tsunami hazard assessment (PTHA), based on the integration of tsunami inundation modeling technology with the analysis and statistical techniques developed for probabilistic seismic hazard assessment. The methodology was applied to Seaside, Oregon, to produce maps of the 100- and 500-year tsunami amplitudes, i.e., tsunami amplitudes with 1% and 0.2% probabilities of exceedance. We will estimate probabilistic tsunami hazards through application of this methodology. In particular, inundation simulations will be conducted that are initiated by a suite of near-field and far-field seismic sources for which the probability of occurrence has been estimated, a model output database will be created, and maps will be developed that provide probability of exceedance estimates for tsunami physical variables associated with tsunami impact on a community, including flow depth, current speed and momentum flux. To estimate tsunami characteristics, we will use the Community Model Interface for Tsunami, or ComMIT (http://nctr.pmel.noaa.gov/ComMIT/), which is a reliable, user-friendly interface for the MOST model that was developed by PMEL and funded by USAID. The specific focus of this effort will be the implementation, testing and documentation of a suite of existing research algorithms to create an operational post-processing tool for ComMIT model output to provide PTHA products, the application of this PTHA tool to the Ocean Shores community, and the documentation of the results (Lead: González)

- Vulnerability Factor: This initial effort focuses on aspects of societal vulnerability that influence the ability of individuals to evacuate tsunami-prone areas prior to inundation. Relevant demographic, land cover, economic, and structural characteristics of our study area will be integrated with tsunami-hazard data to convey spatial aspects of exposure and sensitivity in both absolute (e.g., population counts) and relative (e.g., ordinal rankings) terms. Dasymetric mapping techniques will be employed to disaggregate block-level census data into raster grids that are more-easily integrated with tsunami-hazard outputs (Figure 3). This work builds upon the community-vulnerability assessments outlined in Wood and Soulard (2008), as well as spatial techniques to leverage landcover data (Wood, 2008), geographic-information-system (GIS) software (Wood and Good, 2004), dasymetric mapping (Sleeter and Wood, 2006), and principal component analysis of demographic data (Wood et al., in press) to understand societal vulnerability to tsunamis. The specific focus of this effort will be to transition these research efforts to an operational vulnerability-mapping approach. In addition, we will determine the applicability of structural loss-estimation tools currently found within HAZUS for understanding societal risk to tsunamis, as it relates to evacuation planning and education efforts. The end product will be a map-based assessment (e.g., grid-cell values) that allows emergency managers and community members to understand where societal exposure to tsunamis is greatest and how individuals and assets are sensitive at each location. This output can also be used in later studies focusing on evacuation modeling. (Lead: Wood)

- Community Engagement: Deliberation with affected community members and public officials will occur at several points in our proposed effort. First, we will work with community leaders from the outset to ensure we capture the salient, qualitative aspects of societal vulnerability to tsunami hazards to include in our analysis. Second, we will later work with community leaders to review and determine the utility of map-based and probabilistic assessments in emergency management, public education, and land-use management. Both deliberations will be accomplished through focus group meetings. In addition, a potential collaboration exists with Dr. Eve Gruntfest on community engagement in Ocean Shores, as she is submitting a separate proposal to the National Tsunami Program to examine the use and effectiveness of tsunami risk information and warning products. Dr. Gruntfest is proposing to do her work in Ocean Shores to leverage our existing relationships with community leaders and to help guide our analytical efforts to create new tsunami-risk products. (Lead: Crawford)

Research team background:

- *Frank González* is Affiliate Professor in Earth and Space Science at the University of Washington. He is an experienced tsunami inundation modeler, has published articles on the MOST and other tsunami models, and is an experienced ComMIT user. He was founding Director of the NOAA Center for Tsunami Research and has continued to conduct tsunami research and contribute to international and local community tsunami education since his official NOAA retirement in 2006.

- *George Crawford* recently retired in Jun 2008 from Washington State Emergency Management. During his 13 years at EMD, he served as the Earthquake Program Manager which included program management of the Tsunami and Volcano Program. He is recognized as a national/international expert in tsunami preparedness and has worked with NTHMP states and international communities to develop their tsunami programs. He was the senior Earthquake Program Manager in the United States and was actively involved in developing national policy to support USGS and FEMA tools developed for emergency managers and responders. He continues to develop community based education and training programs as a NOAA contractor.

- *Nathan Wood* is a research geographer for the U.S. Geological Survey and is located in Vancouver, Washington. He is an experienced spatial analyst that has worked with various socioeconomic datasets (both local and national) and spatial methods to characterize societal vulnerability to hazards. He has published articles on the use of GIS, community-based collaborative process, national land-cover data, and principal component analysis to characterize societal vulnerability to tsunamis. In close collaboration with State emergency-management organizations, he has published reports for Oregon, Washington, and Hawaii that document variations in community exposure and sensitivity to tsunamis.

Deliverable

A final report will document the risk analysis methodology and the results of applying the methodology to Ocean Shores, Washington. Elements in the final report will include:

- An operational capability for post-processing of ComMIT model output to provide PTHA products;
- An operational capability for mapping socioeconomic vulnerability metrics;
- A site-specific, map-based tsunami risk assessment for Ocean Shores; and
- Discussion on the applicability and use of loss-estimation tools in local tsunami risk assessments.

Schedule

Six months will be required to complete the project and produce a report that is suitable for publication. Community comments and feedback will be sought throughout the project, and visits to the community will be made as needed. In the first few months, development of the Hazard and Vulnerability Factors can proceed in parallel; in the final few months, these factors will be combined to produce a risk analysis, and the final report will be prepared that documents the methodology and the results of applying it to Ocean Shores, Washington.

Milestone	**Start Month**	**End Month**
Receipt of funds	0.0	
Hazard Factor		
Develop and test the community-specific ComMIT model	0.0	1.5
Test model; Conduct simulations; Create model output database	1.5	3.0
Compute Hazard factor (Probability of exceedance estimates)	3.0	4.0
Vulnerability Factor		
Community meeting and base data collection	0.0	1.0
Spatial analysis: dasymetric mapping, HAZUS, and GIS-based analysis	1.0	3.0
Compute vulnerability metrics	3.0	4.0
Risk Analysis		
Develop Risk Map based on Hazard and Vulnerability Factors	4.0	5.0
Community engagement – *evaluate end products*	4.0	5.0
Write Final Report	5.0	6.0

Budget

A total of $65K will be required for salary, travel and publication costs. The USGS will provide $13K in matching salary and travel funding for Nathan Wood.

Budget Item	**NTHMP Funds**	**USGS Funds**
Salaries		
Frank González	$ 24.0K	
George Crawford	24.0	
Nathan Wood	12.0	$ 12.0K
Travel	2.0	1.0
Publication Cost	3.0	
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Totals	$65.0K	$13.0K

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Figures

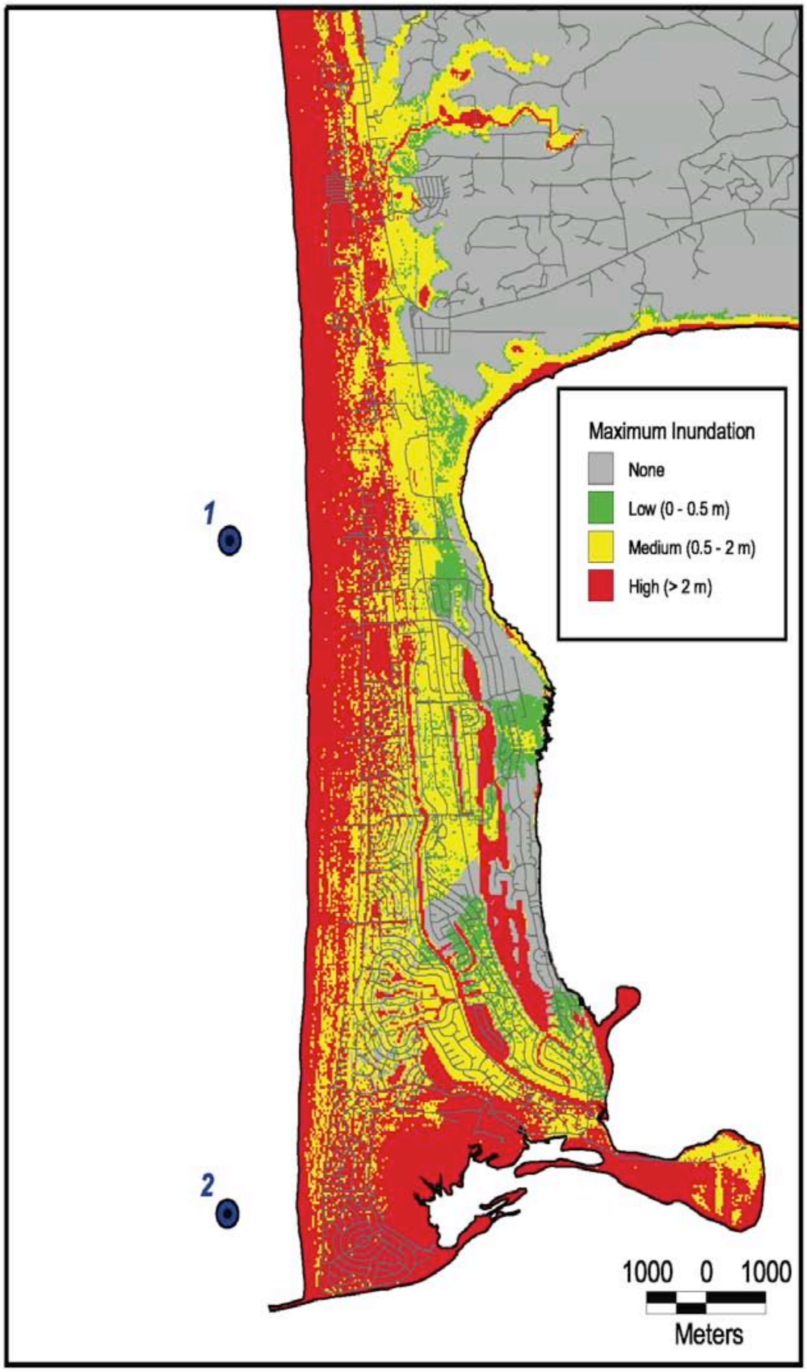

Figure 1. Maximum inundation at Ocean Shores, Washington, resulting from a 9.1 M earthquake in the Cascadia Subduction Zone (after Venturato, et al., 2007).

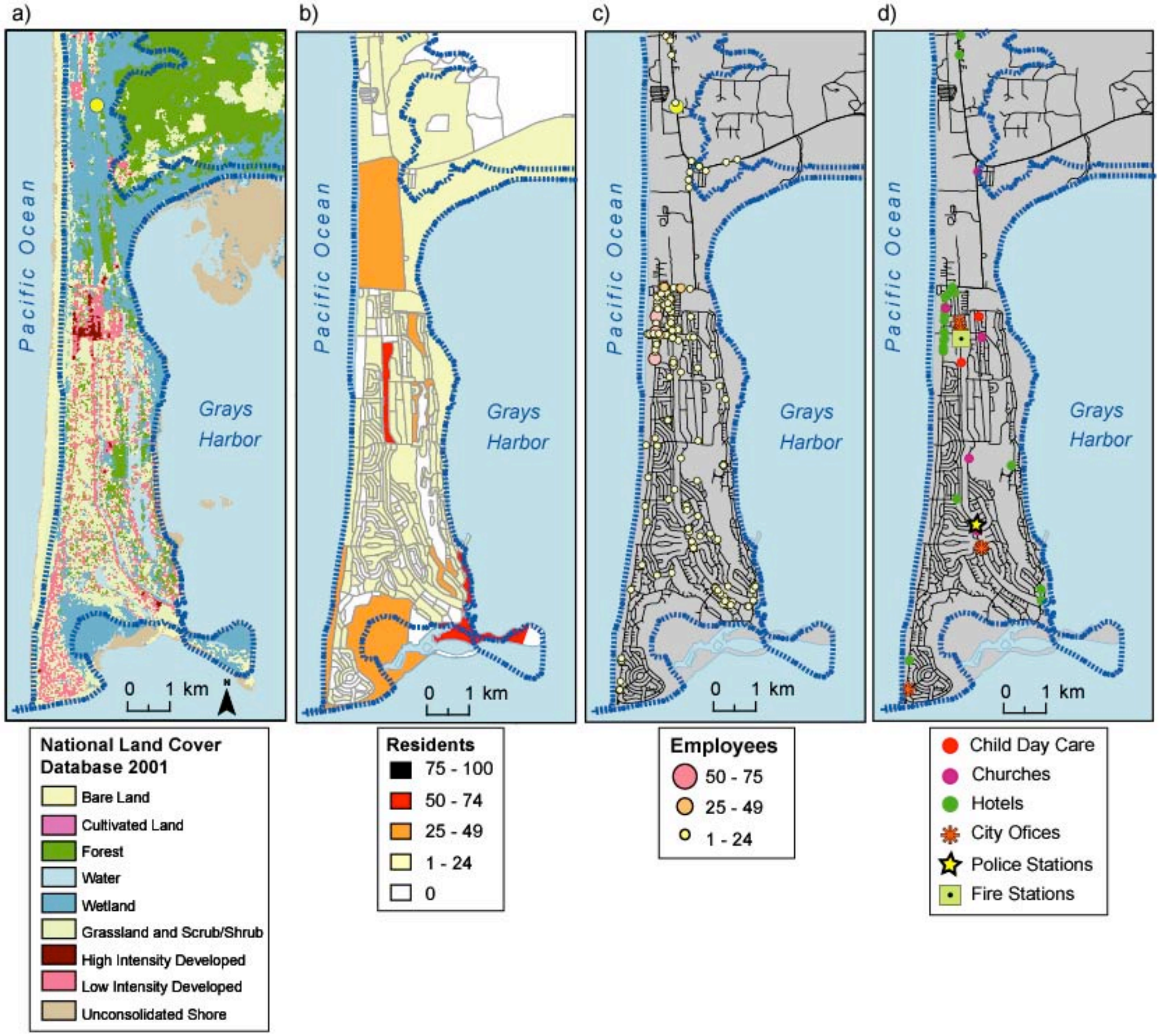

Figure 2. Maps of (a) landcover type, (b) residents, (c) employees, and (d) public venues and critical facilities in the Ocean Shores tsunami-inundation zone. Tsunami inundation estimates are from Walsh et al., 2000, and are depicted here as a blue line encompassing all of Ocean Shores, Washington; attribute information for socioeconomic data can be found in Wood and Soulard (2008).

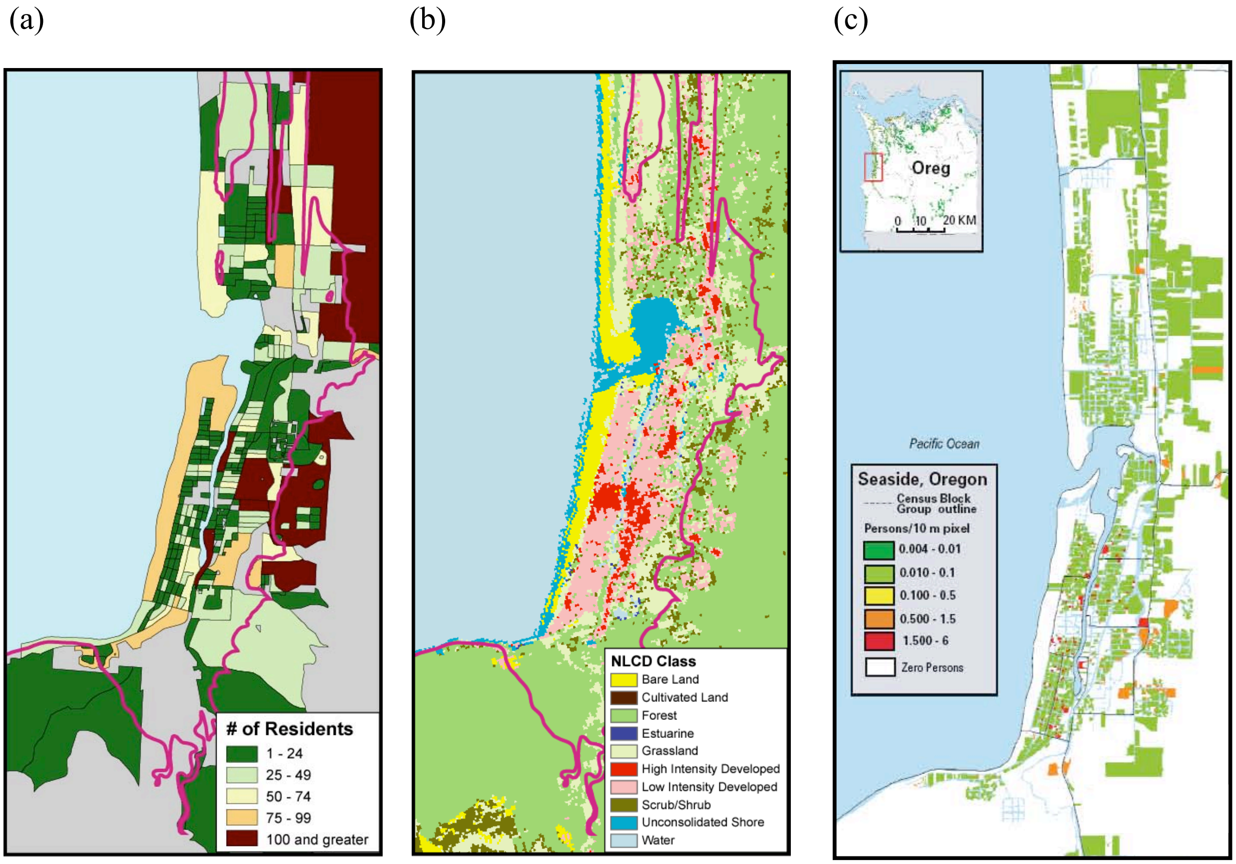

Figure 3. Example of dasymetric mapping techniques that include (a) block-level population counts, based on U.S. Census 2000, (b) landcover types based on the 2001 National Land Cover Database, and (c) the resulting dasymetric population map that integrates maps *a* and *b* to disaggregate census blocks of varying size into a evenly-spaced 30m population grid (see Sleeter and Wood, 2006, for computational methods). The area shown is the City of Seaside, Oregon. The pink line in (a) and (b) is a tsunami-inundation zone developed by DOGAMI to support Oregon Revised Statute 455.446-447.